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IMPROVED MAGNETIC COMPONENTS FOR STATIC INVERTERS AND CONVERTERS

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by

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IMPROVED MAGNETIC COMPONENTS

FOR

STATIC INVERTERS AND CONVERTERS

NAS 3-2792, Amendment 2

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Preface

The following Westinghouse AED personnel have supported this program. Their cooperation is gratefully acknowledged.

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Abstract

A review of the effects of sine flux excitation in the frequency region of 400 cps to 3200 cps on magnetic materials has been made. Magnetic properties and physical properties of magnetic materials are being compiled. Conductors and conductor insulations have been reviewed.

Contract approvals have been obtained for screening magnetic tests on samples, d-c magnetization test points, and interlaminar insulations. Part of the magnetic test equipment has been received, checked out, and assembled. Most of the magnetic materials have been ordered and some material has been received.

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I. INTRODUCTION

The objective of this contract is to obtain improved magnetic components for static inverters and converters.

The magnetic materials, electrical conductors and insulations, and interlaminar insulations used in magnetic components specifically will be evaluated.

The literature is to be reviewed for pertinent data on materials for magnetic components. The environmental conditions to be considered are temperature, radiation, vacuum, shock, vibration, and noise. Operational conditions are to include sine wave and square wave excitation in the frequency range of 400 to 3200 cps. The magnetic materials to be evaluated are magnetic field annealed 49% Co -2% V-49% Fe; doubly grain-oriented, silicon steel (with and without a magnetic anneal); single grain-oriented, silicon steel; square loop 79% Ni-4% Mo -17% Fe; and oriented 50% Ni -50% Fe. The effects of processing are also to be evaluated.

The magnetic properties to be measured with square wave excitation are a-c core loss, a-c apparent core loss, a-c hysteresis, and constant current flux reset points (T, AT, DAT, SAT). The d-c magnetic properties to be measured are B vs. H curves and d-c hysteresis major loops.

Optimum materials and processing for magnetic components are to be selected.

II. MAGNETIC MATERIALS AND CONDUCTORS AND CONDUCTOR INSULATIONS REVIEW

A. Magnetic Materials

1. Effects of Frequencies from 400 CPS to 3200 CPS Using Sine Wave (Sine Flux) Excitation

An alternating exciting current applied to a magnetic material causes a reduction in the effective permeability, increases the energy loss, and introduces a time lag between the field strength and the corresponding induction. A magnetic flux changing with time in a magnetic material causes eddy currents to flow in a direction in the magnetic material opposite to the current flow in the exciting magnetizing coil. This effect is illustrated in Figure 1. These eddy currents depend upon the magnetic material geometry, resistivity, and permeability. The frequency of the alternating flux also affects the eddy currents. The effect of the eddy currents in the magnetic field is to concentrate the field at the surface of the material. This surface concentration of the magnetic field strength reduces the effective flux. For this reason, magnetic cores subjected to exciting alternating current are laminated, each lamination being electrically insulated. The electrical insulation requirement of the interlaminar insulation depends upon the contact surface area of the lamination, the stacking pressure on the laminations, the actual flux density of each area of the lamination, and the alternating current frequency.

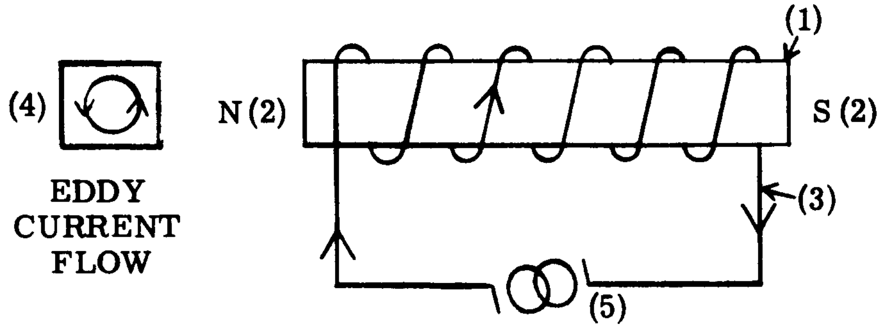
The classical theory states that the eddy-current loss at intermediate and high inductions increases as the square of the frequency and the hysteresis loss is proportional to the first power of the frequency. This theory conventionally applies to flux densities in the range of 2000 to 12,000 gauss where the permeability varies markedly with the field. The calculation of separation data in this region of flux density is limited to frequencies of less than 100 cps, permeabilities of less than 5000, and to isotropic materials.

The hysteresis loss equation is:

$$P_h = \left(\frac{W}{D \cdot 10^7}\right) f_1 \eta B^x \text{ watts}$$

The eddy loss equation is:

$$P_e = \left(\frac{1.645 d^2 W}{D \cdot 10^{16}}\right) (f_2)^2 B^2 \lambda \text{ watts}$$



(1) Magnetic Lamination
(2) Magnetic Poles
(3) Current Flow
(4) Eddy Current Flow in a Magnetic Material, End View, During Half Cycle
(5) Alternator

Figure 1. Eddy Currents in a Magnetic Material Subjected to Cyclic Magnetization

The total core loss is:

$$P_c = P_h + P_e \text{ watts}$$

where B = flux density, in gausses

D = density of core material

d = thickness of core lamination, in cm

f = frequency, in cycles per second

W = weight of core, in grams

η = hysteresis loss coefficient

λ = eddy loss coefficient

x = hysteresis loss exponent for B

The frequencies f_1 and f_2 should be as close as possible to the desired application frequency.

The thickness of the lamination material affects the total core loss of the material. This effect varies as the square of the thickness in thick laminations (0.060 in.) and as a smaller power when the thickness is smaller.

These classical equations and assumptions do not hold true in all cases, especially in very thin materials ($<$0.005"), large grain size materials, anisotropic magnetic materials, and in materials of high purity. The number of magnetic domains present in a magnetic material and the width of the "Bloch" wall are also assumed to cause deviations from classical core-loss calculations.

The hysteresis loss in a very thin magnetic material with few domains, a high degree of magnetic anisotropy and high purity is affected largely by the energy required to nucleate domain walls at the surface of the material.

The flux reversals in a magnetic material caused by an alternating current occur in the discrete width of a "Bloch" wall between adjacent magnetic domains with different magnetization vectors. Therefore, the eddy current loss is concentrated in the area of the "Bloch" wall causing inhomogeneity in the distribution of the loss. An overall increase in the eddy current loss occurs as a result of this inhomogeneity.

The effects discussed above indicate the difficulty of absolute predictions of the effects of existing magnetic materials under either square wave, sine wave (sine flux), sine current, or d-c ballistic conditions. The effects of varying frequency of a-c excitation from 400 to 3200 cps also is not absolutely predictable, due to eddy and hysteresis loss anamolies. In fact, one could postulate that all a-c core loss is due to eddy current loss if no magnetomechanical losses are present.

2. Data Compilation

Data on magnetic and physical properties of magnetic materials to be evaluated have been partially tabulated. The data are shown in Table I. These data will be updated with the data obtained in this contract for comparison purposes in the final report.

B. Conductors and Conductor Insulation Review

Electrical conductor insulations including Anacote (resin bonded glass and refractory oxide frit); Anadur (fiber glass, glass, and resin bonded refractory oxide frit); Westinghouse 2554B (resin bonded glass and refractory oxide frit); P-D Ceramic-eze (glass enamel with refractory oxide overcoated with Teflon); H-film; and ML enamel were reviewed. This task is now complete and will be reported when the reports on Contract NAS 3-4162 have been approved.

The evaluation of aluminum foil and strip conductors as used in the static inverter being developed by Westinghouse for North American under NASA Contract 9-150 is completed.

In the last few years considerable developmental effort has been expended on foil winding of transformer coils. In the beginning, the effort was sponsored mainly by the aluminum manufacturers, but now industry is beginning to utilize aluminum foil windings in transformers.

Aluminum foil has disadvantages and the early development was to attempt to overcome these disadvantages which are:

1. Lower volume conductivity compared to copper.
2. Problems with lead connections.

Winding with aluminum foil has the following advantages which are:

1. Conductivity to weight ratio is better compared to copper.
2. Ease of winding.

TABLE I. Magnetic and Physical Properties of HY-RA 80, Hipernik V, Supermendur, Orthosil and Cubex

Material	Density (gms/cc)	Tensile Strength (psi) Longitudinal	Tensile Strength (psi) Transverse	Compressive Strength (psi) Longitudinal	Compressive Strength (psi) Transverse	Thermal Expansion in/in/°C	Chemical Composition	Crystalline Structure and Orientation	Electrical Resistivity ρ Microhm-cm	Curie Points C
HY-RA 80 Square Permalloy 80	8.74					12.9×10^{-6} -70° to 200°	69% Ni 4% Mo Bal. Fe	F.C.C. Isotropic	58	460
HIPERNIK V Square Orthonol	8.25	55,000 annealed				10×10^{-6} 0° to 500°	50% Ni 50% Fe	F.C.C. [001] in direction of rolling (100) in plane of material	45	500
SUPERMENDUR	8.20					9.9×10^{-6} 20° to 100°	49% Co 49% Fe 2% V	B.C.C. Ordered structure 70-80%	26	940
ORTHOSIL MAGNESIL	7.65	51,500 annealed	59,600 annealed				3.25% Si Bal. Fe	B.C.C. Singly Grain Oriented, [001] in direction of rolling, (110) in material plane	50	750
CUBEX	7.65	40,200 annealed	40,200 annealed	37,120 annealed		12.7×10^{-6} 20°	3.00% Si Bal. Fe	B.C.C., [001] in direction of rolling, (100) in plane of material. Doubly grain-oriented.	48.5 at 22.2°C 78.0 at 371°C 87.5 at 482°C	757

Material	Magneto-Striction $\Delta L/L$	Saturation Induction, B_S (KG)	Initial Permeability μ_0	Incremental Permeability μ_Δ	Maximum Permeability μ_m	Coercivity H_{cs}, Oersteds	Hysteresis Loss, Normal P_h ergs/cm.^{3}/cycle
HY-RA 80 Square Permalloy 80	0.6×10^{-6} at 6 KG longitudinal	8	25,000		500,000	.02 - .04 2 mil	
HIPERNIK V Square Orthonol		16	500		100,000-200,000	.04 - .2 2 mil	500 at B_m-15 KG
SUPERMENDUR	66×10^{-6} at 24 KB longitudinal	24	2,500		66,000-80,000	.15 - .35 2 mil	
ORTHOSIL MAGNESIL	25×10^{-6} at 20 KG longitudinal	20	1,000 2 and 4 mil		15,000 (2 mil) 20,000 (4 mil)	.4 to .7 2 and 4 mil	
CUBEX	25×10^{-6} at 20.3 KG	20.3	4,000		30,000-50,000	.05 to 1.5	

3. Better space factor with the proper insulation.
4. Better cooling with virtual elimination of hot spots.
5. Lower voltage stresses (turn to turn only).

The electrical volume conductivity of 99.45 percent aluminum (EC Alloy) is 62 percent IACS, O_2 and H_{19} tempers, or approximately 64 percent more aluminum by volume is required for equivalent resistance. Aluminum with the larger volume but lower density results in a winding having about 50 percent the weight of a copper winding. Lead connections can be made adequately but there is a problem of cost and multiple connections.

The mose difficult problem to overcome in Aerospace applications is turn to turn insulation where the conductor thickness is small. In aerospace applications, it is necessary to operate transformers at the maximum temperature possible with regard to operating conditions, reliability, and life. One of the earlier materials used for turn to turn insulation was mylar which is a Class B insulation and good only to about 150°C. The use of mylar was limited in temperature and had poor mechanical properties in the very thin gauges. An anodic coating proved to be satisfactory with regard to operating temperature and insulation thickness, but it has considerable room for improvement. Some of the disadvantages of the anodic coating are poor flexibility resulting in crazing of the coating, poor quality of coating, burred foil edges, little resistance to foreign material in the winding, and high cost of coating thin gauges. Another insulation being used is a coating of duPont ML Enamel on one side of anodized aluminum. This ML coated material has good performance but it is very expensive.

Commercial distribution transformer manufacturers are beginning to use aluminum foil. Since weight is generally not critical in distribution transformers, the main goal is to utilize the other advantages of alumin foil. Because aluminum is more ductile than copper, it forms better, creating a tighter wound unit. Aluminum strip conductor is easier to wind than copper wire, reducing manufacturing costs. Because of its better cooling properties, strip wound coils permit greater overloads. Westinghouse Transformer Division in Sharon, Pennsylvania, is using aluminum strip insulated with an epoxy enamel and are producing facilities to do their own coating. The insulation is limited in temperature as it is a Class B material.

Recent developments of polyimid and polyamid insulating materials by duPont have created a new possibility for turn to turn insulation materials. The materials are Kapton and Nomex with Kapton being available to a thickness of 0.0005 and Nomex to a thickness of 0.002. Both materials are high temperature materials and have very good thermal, electrical, and mechanical properties. These materials can be used as interleaving insulation between turns. With these materials, it is expected that a good high temperature, lighter weight, and lower cost transformer will be possible. The interleaving eliminates the high cost of the present high temperature insulation methods, and provides an uninsulated conductor for versatility and ease of making connectors. (See references [1] [2] .)*

[ ]* Figures in square brackets refer to individual references listed in Appendix B.

III. CONTRACT APPROVALS

The NASA Program Manager has approved the recommendation that aluminum orthophosphate be used as the interlaminar insulation on samples used in degradation and vacuum testing phases of this program. A review of such interlaminar insulations as M. A. B. (mica, aluminum orthophosphate, and bentonite), aluminum orthophosphate, calcium oxide, magnesium oxide, calcium hydroxide, magnesium hydroxide, iron oxide (Fe_2O_3), aluminum oxide, magnesium silicate, glasses, magnesium phosphate, sodium tetraborate, colloidal silica in magnesium oxide, and core plate enamels was made before aluminum orthophosphate was selected based upon its sublimation rate in vacuum of 10^{-6} torr and its resistance to operating temperatures of 250°C.

The NASA Project Manager has approved the measurement of G, gain, as the screening test for oriented 50% Ni - 50% Fe, square loop 79% Ni - 4% Mo - 17% Fe, and magnetic field annealed Supermendur. Each material will be tested at 400 cps and H_m, peak magnetizing force of 1 oersted for 50% Ni - 50% Fe, 0.5 oersted for 79% Ni - 4% Mo - 17% Fe, and 5 oersteds for Supermendur.

The measurement of P_c, total core loss, at 400 cps and 10 kilogauss has also been approved as the screening test for Cubex and 3% silicon steel, singly grain oriented.

The best two out of three core samples of each material will be selected in the screening tests on the basis of either lowest P_c, total core loss, or highest G, gain. The selected cores will then be used in the full magnetic test program.

The NASA Program Manager has approved the following test points for d-c magnetization curves.

Material	Temperature °C	H (oersted)
Supermendur (magnetic field annealed)	-55	Not available
	Room Ambient	0.1, 0.15, 0.2, 0.25, 0.3, 0.5, 1, 250
	250	Not available
Cubex (with and without magnetic field anneal)	-55	0.1, 0.3, 0.4, (5 points not available)
	Room Ambient	0.1, 0.3, 0.4, 1.5, 4, 10, 25, 250
	250	0.1, 0.3, 0.4, (5 points not available)

Material	Temperature °C	H (oersted)
79% Ni-4% Mo-17% Fe (Square Loop)	-55	Not available
	Room Ambient	0.01, 0.02, 0.035, 0.05, 0.1, 0.3, 1, 10
	250	Not available
50% Ni-50% Fe (Oriented)	-55	0.02, 0.04, 0.05, 0.06, 0.1, 0.2, 0.4, 50
	Room Ambient	0.02, 0.05, 0.06, 0.08, 0.1, 0.2, 0.4, 50
	250	0.02, 0.05, 0.07, 0.1, 0.2, 0.4, 1, 50
3% Silicon Steel (Single grain orientation)	-55	Not available
	Room Ambient	0.01, 0.03, 0.05, 0.15, 1, 5, 15, 100
	250	0.01, 0.03, 0.05, 0.15, (4 points not available)

Where the actual test points are not available, the test points will be the same as room temperature, modified as required to produce acceptable d-c magnetization curves.

IV. MATERIALS ORDERED

The following materials have been ordered:

Trade Name	Description*
Cubex	1) 2 mil round toroids, Alkaphos coated 2) 2 mil round toroids, magnetic field annealed, Alkaphos coated 3) 6 mil strip 4-3/4" wide, Alkaphos coated
Supermendur	1) 2 mil round toroids, magnetic field annealed with MgO insulation 2) 4 mil strip, 4" wide, uncoated 3) 6 mil strip, 4" wide, uncoated
Orthosil	1) 6 mil strip, 4" wide, uncoated
Hipernik V	1) 2 mil round toroids, MgO insulated 2) 4 mil round toroids, MgO insulated 3) 4 mil strip, 4" wide, uncoated
Square Orthonol	1) 2 mil round toroids, MgO insulated 2) 4 mil round toroids, MgO insulated 3) 6 mil strip, 4" wide, uncoated
Hy-Ra 80	1) 2 mil round toroids, MgO insulated 2) 4 mil round toroids, MgO insulated 3) 4 mil strip, 4" wide, uncoated
Square Permalloy 80	1) 2 mil round toroids, MgO insulated 2) 4 mil round toroids, MgO insulated 3) 6 mil strip, 4" wide, uncoated
Magnesil	1) 2 mil round toroids, MgO insulated 2) 4 mil round toroids, MgO insulated 3) 4 mil strip, 4" wide, uncoated

*The round toroids will have wound tape with 3.890" outside diameter, 3.256" inside diameter, 1" height. Weight $\sim$ 1 lb. The aluminum core boxes are to be filled with silicone oil, hermetically sealed, and insulated with epoxy resin.

V. EQUIPMENT

A Weston Inductronic Wattmeter, a modified version of Model 1483, and a Weston current transformer, Model 327, have been received. This wattmeter is a unit having an electrodynamometer input circuit and an output system using principles of induction and electronics to produce a d-c current which is in precise proportion to the input. A panel meter is provided for quick indication of the percentage output current, a d-c current of 1 ma is full scale output. The full scale voltage is 100 mv. For precise measurements d-c signals, both voltage and current, in exact proportion to the input are available at suitable binding posts.

Full scale wattage is equal to, and full scale output is proportional to, the normal current times the normal voltage times unity power factor. The normal current is 5 amp and the normal voltage is 50V, 100V, or 200V. The maximum voltage is 1 kw.

The estimated accuracy at 20 kc and unity power factor are ± 3% of full scale value. The instrument can be used up to 50 kc without damage.

The frequency-power factor influence is:

	Max. Error % of Full Scale
1. Rated accuracy on d-c	0.1
2. Frequency influence at unity power factor (transfer error)	
a. d-c to 60 cps	Negligible
b. d-c to 2500 cps	0.13
3. Power factor influence, leading or lagging power factor	
a. 1 to 0.5 PF (60 cps)	0.04
b. 1 to 0.5 PF (2500 cps)	0.4
c. 1 to 0.1 PF (60 cps)	0.2
d. 1 to 0.1 PF (1000 cps)	0.5

The following additional equipment has been acquired by Westinghouse to test toroids for CCFR properties using half-wave square current excitation instead of half-wave sinusoidal current excitation and also other magnetic properties under square flux instead of sine flux conditions using full wave conditions:

1) Ballantine Peak Voltmeter, 305A (two units)
2) Mosely Autograf D-C Voltmeter, Model 22
3) K & S D-C Regulated Power Supply
4) HP Electronic Counter, Model 521 CR
5) HP Oscilloscope, Model 130B
6) Ballantine D-C, A-C Precision Calibrator, Model 421
7) CML Sine or Square Wave Power Supply with CML Sine or Square Wave Oscillator

The following Westinghouse equipment will also be used:

1) HP RMS Voltmeter, Model 3400A
2) HP 400H Average Reading Voltmeter
3) NJE D-C Power Supply
4) V. A. W. meter shunts
5) SR Magnetic Testing Set, Model MAT

VI. PLANS FOR FUTURE WORK

In the next quarter, the remainder of the magnetic test samples will be received. The magnetic test equipment will be assembled and calibrated. The magnetic testing of the samples will be initiated. The acoustic tests will be completed.

VII. BIBLIOGRAPHY

1. Goodman, Ernest A., "Characteristics of Sheet Windings in Transformers", Elec. Engrg., November 1963

2. "New Distribution Transformers with Enameled Foil", Insulation, July 1964

SECTION VIII

APPENDIX A

Symbols and Definitions

Symbols and Definitions

PART I

A. Symbols Used in Magnetic Testing*

B - Normal induction, magnetic induction, or magnetic flux density

B_d - Remanent induction

B_{dm} - Remanence

B_m - Maximum induction in a hysteresis loop

B_r - Residual induction

B_s - Saturation induction

H - Magnetizing force, magnetic field strength

H_c - Coercive force

H_{cs} - Coercivity

P_c - Total core loss

P_h - Normal hysteresis loss

P_e - Eddy current loss

μ - Normal permeability

μ_Δ - Incremental permeability

μ_m - Maximum permeability

μ_o - Initial permeability

*See page WAED 65.6E-19

B. Definitions of Terms Used in Magnetic Testing*

Coercive Force, H_c

The d-c magnetizing force at which the magnetic induction is zero when the material is in a symmetrically cyclically magnetized condition.

Coercivity, H_{cs}

The maximum value of coercive force.

Core Loss (Total), P_c

The power expended in a magnetic specimen in which there is a cyclically alternating induction, normally sinusoidal.

Eddy Current Loss, Normal, P_e

That portion of the core loss which is due to induced currents circulating in the magnetic material subject to a symmetrically cyclically magnetized excitation.

Hysteresis Loss, Normal, P_h

The power expended in a ferro-magnetic material, as a result of hysteresis whenthe material is subjected to a symmetrically cyclically magnetized excitation.

Inducation, Normal, B

The maximum induction, in a magnetic material that is in a summetrically magnetized condition.

Induction, Remanent, B_d

The magnetic induction that remains in a magnetic circuit after the removal of an applied magnetomotive force.

Induction, Residual, B_r

The magnetic induction corresponding to zero magnetizing force in a magnetic material that is in a symmetrically cyclically magnetized condition.

*See page WAED 65.6E-19

Induction, Saturation, B_s

The maximum intrinsic induction possible in a material.

Magnetizing Force (Magnetic Field Strength), H

That magnetic vector quantity at a point in a magnetic field which measures the ability of electric currents or magnetized bodies to produce a magnetic induction at the given point.

Permeability, Incremental, μ_Δ

The ratio of a cyclic change in magnetic induction to the corresponding cyclic change in magnetizing force when the mean induction differs from zero.

Permeability, Initial, μ_o

The limiting value approached by the normal permeability as the applied magnetizing force, H, is reduced to zero.

Permeability, Maximum, μ_m

The maximum value of normal permeability for a given material.

Permeability, Normal, μ

The ratio of the normal induction to the corresponding magnetizing force.

Remanence, B_{dm}

The maximum value of the remanent induction for a given geometry of the magnetic circuit.

*ASTM STANDARDS, PART 8, 1964, ASTM Designation: A 350-64, "Standard Definitions of Terms, Symbols, and Conversion Factors Relating to Magnetic Testing."

PART II

A. Symbols Used in CCFR Testing of Toroidal Magnetic Amplifier Cores. *

AT	- Same as H_1
B_m	- Peak induction or peak flux density
$2B_m$	- Maximum flux density swing
B_r	- Residual induction or residual flux density
B_m-B_r	- Squareness
$\frac{B_r}{B_m}$	- Squareness ratio
Δ B	- Delta induction or delta flux density
ΔB_0	- Delta induction, fixed
ΔB_1	- Delta induction, fixed
ΔB_2	- Delta induction, fixed
CCFR	- Constant current flux reset
DAT	- Same as Δ H
G	- Gain
H_m	- Peak magnetizing force
H_0	- Magnetizing force, dependent
H_1	- Magnetizing force, dependent
H_2	- Magnetizing force, dependent
Δ H	- Incremental magnetizing force
SAT	- Same as B_m
T	- Same as $\frac{B_r}{B_m}$

*See page WAED 65.6E-23

B. **Definitions Used in CCFR Testing of Toroidal Magnetic Amplifier Cores.** *

Constant Current Flux Reset, CCFR

This test employs an excitation current consisting of half-wave sine current pulses of sufficient and constant magnitude to drive the core flux into positive saturation. A direct-current magnetizing force of adjustable magnitude is applied to the core so as to reset the magnetic flux away from positive saturation during the intervals between pulses of excitation current. The resultant cyclic flux change is measured by means of a sensitive flux voltmeter connected to a separate pickup winding on the core.

Flux Density Swing, Maximum; $2B_m$

The maximum flux density swing equal to the absolute total value of positive and negative peak induction or $2\ B_m$. ($2\ B_m = 2$ SAT)

Gain, G

$G = \dfrac{\Delta B_2 - \Delta B_1}{\Delta H}$, a measure of loop steepness in terms of incremental permeability.

Induction, Delta (Delta Flux Density); ΔB

Delta induction is the change in induction (flux density) when a core is in a cyclically magnetized condition.

Induction, Fixed Delta; ΔB_1, ΔB_0, ΔB_2

1. $\Delta\ B_1$ - delta induction equal to one third of $2\ B_m$, maximum flux density swing.

2. $\Delta\ B_0$ - delta induction equal to one half of $2\ B_m$, maximum flux density swing.

3. $\Delta\ B_2$ - delta induction equal to two thirds of $2\ B_m$, maximum flux density swing.

*See page WAED 65.6E-23

Induction, Residual (Residual Flux Density), B_r

Residual induction is the magnetic induction at which the magnetizing force is zero while the material is cyclically magnetized with a half-wave sinusoidal magnetizing force of a specified peak magnitude. (This definition differs from the standard definition which requires symmetrically cyclically magnetized conditions).

Induction, Peak (Peak Flux Density), B_m

Peak induction is the magnetic induction corresponding to the peak applied magnetizing force. The peak induction will usually be slightly less than the true saturation. (B_m = SAT)

Magnetizing Force, Dependent; H_1, H_0, H_2

1. H_1 - The d-c reset magnetizing force required to produce a cyclic change of induction ΔB_1 (H_1 = AT).
2. H_0 - The d-c reset magnetizing force required to produce a cyclic change of induction ΔB_0 (H_0 = AT + 1/2 DAT).
3. H_2 - The d-c reset magnetizing force required to produce a cyclic change of induction ΔB_2 (H_2 = AT + DAT).

Magnetizing Force, Incremental; ΔH

The incremental change in magnetizing force equal to $H_2 - H_1$. (ΔH = DAT)

Magnetizing Force, Peak; H_m

Peak magnetizing force is the maximum value of applied magnetomotive force per mean length of path of the core.

Squareness; $B_m - B_r$

The delta B induction change between the peak induction, B_m, and the residual induction, B_r.

Squareness Ratio; $\frac{B_r}{B_m}$

The ratio of residual induction, B_r, over peak induction, B_m

$$\left[\frac{B_r}{B_m} = 1 - \left(\frac{B_m - B_r}{B_m}\right) = T\right]$$

*Where applicable, AIEE, No. 432 (Jan. 1959) "Test Procedure for Toroidal Magnetic Amplifier Cores" has been used.

PART III

General Definitions of Terms

Acoustic

Pertaining to the science of sound.

Aluminum Foil

Thin aluminum material less than 0.006 inch thick.

Aluminum Strip

Aluminum strip is greater than 0.006 inch thick.

Atomic Ordering

Forming a superlattice which is an ordered arrangement of atoms in a solid solution superimposed on the normal solid solution lattice.

Base Line Property

Those initial magnetic, physical or mechanical properties that are normally present at room temperature, i.e. - saturation induction, thermal expansion, tensile strength.

B.C.C.

Body centered cubic structure.

Bloch Wall

The boundary between adjacent domains of different magnetization vectors or anti-parallel electron spins in which the electron spins of each atom in the wall are slowly changed so as to affect the complete change in magnetization vectors between adjacent domains. The Bloch wall width is determined by the individual ferromagnetic material and is a discrete width. The energy of the wall is variable depending upon the angle between adjacent domains and the crystallographic plane of the wall.

Centistoke

A unit of kinematic viscosity.

Critical Temperature

The temperature at which a change in crystal structure, phase or physical properties occurs under constant pressure conditions.

Converter

A device which changes or converts a-c current to d-c current.

Disordered Structure

The crystal structure of a solid solution in which the atoms of different elements are randomly distributed with respect to the available lattice sites.

Domain

A small region, in ferromagnetic materials, where the atomic magnetic moments are all aligned parallel to one another.

Dose (Integrated Flux)

The total radiation exposure to which the specimen has been subjected (expressed as the number of particles per square centimeter).

Double Window Transformer

A transformer built from laminations from which two square openings have been punched.

Doubly Grain-Oriented Silicon Steel

An iron base alloy containing about 3 percent silicon where the phase that is present (α iron) is body centered cubic. The individual re-crystallized grains of this alloy are oriented such that the cube face plane is in the plane of the material and a cube edge direction is parallel to the rolling direction.

F.C.C.

Face centered cubic structure.

Field

The space where an electric or magnetic force is being exerted.

High Vacuum (Space Vacuum)

This term, as used in this report, refers to a vacuum equal to or higher than 10^{-6} torr (m.m. Hg).

Inverter

A device which changes d-c current to a-c current.

Isotropic

Having the same properties in all directions.

Magnetic Field Annealing (MFA)

Annealing a magnetic material in the presence of a magnetic field so as to align the magnetic domains in a direction parallel to the field.

Magnetostriction

A change in the dimensions of a body when magnetized.

Neutron

One of the elementary particles which, together with the proton, comprises the nucleus of all elements. It has no charge.

Ordering Temperature

The temperature at which atomic ordering of different elements occurs.

Proton

One of the elementary particles which, together with the neutron, comprises the nucleus of all elements. It has a positive charge.

Resistivity, Electrical, P

Electrical resistivity of a material.

Rowland Ring

A continuous ring of magnetic material of uniform radial width and cross-sectional area with no joints or welds. The ratio of its mean diameter to its radial width is ten to one or greater.

Singly Grain-Oriented Silicon Steel

An iron base alloy containing approximately 3-1/4 percent silicon where the phase that is present is body centered cubic α iron.

The individual recrystallized grains of this alloy are oriented in the rolling direction such that the cube edge direction and the rolling direction are parallel. The face diagonal plane is in the plane of the material.

Stress Relief Annealing (SRA)

Heating to a suitable temperature, holding long enough to reduce residual stresses and then cooling slowly enough to minimize the development of new residual stresses.

Structure Sensitive Properties

The properties that are structure sensitive in magnetic materials are permeability (μ), coercive force (H_c), and hysteresis loss (P_h). The factors that affect these properties are composition, impurities, strain, temperature, crystal structure and crystal orientation.

Tape

A thin strip of magnetic material a few mils thick which is normally wound into the shape of a round core.

EXPENDITURES AND COMMITMENTS

Contract No.:	NAS 3-2792, Amendment 2
For:	Improved Magnetic Components for Static Inverters and Converters
Reporting Period:	9.27.64 to 12.28.64 (Sixth Quarter)
Expenditures Through 5th Quarter:	$93,352
Amd. 1, 6th Quarter:	11,998
Amd. 2, 6th Quarter:	14,005
Total Expenditures to Date:	$119,355
Outstanding Commitments:	$ 3,094.59

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